RF Analysis

Systems Engineering

Synopsis

The upgrade to the UD4 cabinet introduces inserting an RF power splitter with a COHO burst mixer into the IF signal path. Initial analysis showed the addition of passive RF components would reduce the STALO signal by 3.5 dB due to attenuation and insertion losses. A revised design change replaced the RF splitter with a 6 dB directional coupler, which has a lower path loss of 1.8 dB.

A path loss analysis was done from data collected from EHB technical manuals, manufacturers' specification sheets, source control drawings and actual measurements. The signal strength path was then calculated from path losses caused by each RF component. These values were then compared to the expected optimal range to determine whether a significant path loss could affect the IF digitizer. The results indicated a 6 dB directional coupler would cause the STALO signal to be only 0.5 dB below the minimum mixer/preamp specifications.

To verify the STALO path loss, an attenuation test on Legacy equipment was conduct by Bill Urell. His results indicated attenuating the STALO signal up to 3.7 dB did not affect the overall system noise temperature or dynamic range.

Several options were analyzed on the most feasible RF component design to implement in the UD4 cabinet. The systems engineering team concluded that a 6 dB directional coupler was the most logical choice because of its functionality and cost.

Analysis

The path losses through and RF signal strength at the output of each RF component in the UD2 and UD4 cabinets are provided. Table 1 provides path loss information for the critical receiver path. Table 2 provides information for test path. Both theoretical losses and actual field data losses are provided in Tables 1 and 2.

RF component	Theoretical[1] Path Loss (dB)	Field Data[2] (dB)
UD4 cabinet		
4A1 Xmtr RF (source power dBm) 4A1 STALO (source power dBm) 4A1 Test RF (source power dBm) 4A1 COHO (source power dBm)	13.00 ± 1.25 15.00 ± 0.75 23.00 ± 1.75 27.00 ± 1.00	13.00 ± 1.25 15.35 ± 0.70 22.54 ± 0.62 26.77 ± 0.41
26 dB attenuator IFD (New RF components)	-26.00 ± 0.50	-26.00 ± 0.50
6 dB directional coupler STALO 1 out (New RF components) 6 dB directional coupler STALO 2 out (New RF components)	-6.00 -1.80	-6.00 -1.80
20 dB attenuator (New RF components)	-20.00 ± 0.50	-20.00 ± 0.50
Pulsar Burst Mixer RF (New RF components) Pulsar Burst Mixer STALO (New RF components) Pulsar Burst Mixer IF (New RF components)	-6.00 ± 0.20	-6.00 ± 0.20
4A36 Optional attenuator	0.00	-0.59 ± 0.80
4DC2 20 dB directional coupler	-0.50 ± 0.20	0.00
4A4 Pre-select bandpass filter	-2.25 ± 0.65	-2.22 ± 0.37
4A5 20 dB gain mixer/amplifier	20.00 ± 0.50	19.79 ± 0.50
IFD 3 dB attenuator (New RF components)	-3.00 ± 0.50	-3.00 ± 0.50
AT33 6 dB attenuator	-6.00 ± 0.30	-5.85 ± 0.26
4A20 4 way splitter *RF signal to Burst mixer path* (J5) out	-6.00 ± 0.50	-6.35 ± 0.21
UD2 cabinet		
2A3 Receiver protector	-1.00 ± 0.20	-0.65 ± 0.23
2A1A3FL1 Bandpass filter	-0.50 ± 0.20	-0.50 ± 0.20
2A4 Low noise amplifier (28 dB gain)	28.00 ± 0.50	27.88 ± 0.47

Table 1: RF and IF Path Losses[1]

[1]Based upon Source control drawings: Path losses = Attenuation + Insertion Losses
[2]"NWS: EHB-6, Maintenance, Note 30"

UD4 Cabinet	Theoretical[1] Path Loss (dB)	Field Data[2] (dB)
UD4 cabinet		
AT33 6 dB attenuator	-6.00 ± 0.30	-5.85 ± 0.26
4A20 4 way splitter *KD Test path* (J2) 4A20 4 way splitter to 4A26 Power sensor (J3) 4A20 4 way splitter to RF sample jack (J4)	-6.00 ± 0.50 -6.00 ± 0.50 -6.00 ± 0.50	-6.33 ± 0.20 -6.38 ± 0.22 -7.27 ± 0.53
AT34 10 dB attenuator	-10.00 ± 0.50	-10.23 ± 0.23
4DC1 40 dB directional coupler	-0.50 ± 0.20	0.00
4A21 Microwave delay line	-50.00 ± 0.50	-44.84 ± 1.79
4A22 4 position diode switch 14 dB gain *KD Test path* (J1) in 4A22 4 position diode switch *RFD Test path* (J2) in 4A22 4 position diode switch *CW Test path* (J3) in 4A22 4 position diode switch *Noise Test path* (J4) in	14.00 ± 1.00 -2.50 ± 0.50 -2.50 ± 0.50 -2.50 ± 0.50	13.51 ± 1.04 -1.86 ± 0.34 -1.97 ± 0.31 -2.05 ± 0.38
4A23 RF test attenuator (6 dB loss)	-6.00 ± 0.50	-6.01 ± 0.45
4A24 2 position diode switch (J2) 4A24 2 position diode switch (J3)	-2.50 ± 0.50 -2.50 ± 0.50	-1.95 ± 0.20 -1.56 ± 0.21

Table 2: RF Test Path Losses[1]

[1] Based upon Source control drawings: Path losses = Attenuation + Insertion Losses
[2]"NWS: EHB-6, Maintenance, Note 30"

This analysis is based on field data and manufacturer data sheets listed in Tables 3 through 6. The transmitter parameters and path losses are shown in Table 3 thru Table 6 along with a block diagram of the receiver path losses, which is shown in Figure 1. The path losses are based upon actual measurements recorded from different radar sites.

Klystron transmitter output at 700 kW peak	88.45 dBm
Duty cycle for a short pulse at 1013.5 Hz and 1.54 X 10^{-6} s pulse duration	-28.12 dB
Incoming receiver signal at receiver protector (Reference signal)	-40.00 dBm
UD3 Path loss of Klystron to AT4 High power attenuator	-39.00 dB
Cable loss of UD3 to AT 33 6 dB attenuator	-0.67 $\pm$ 0.14 dB

Table 3: Transmitter Parameters

Klystron to IFD (J2) Input Path	Path Loss (dB)
Klystron to AT33 input	-39.00
AT33 6 dB attenuator	-5.85
4A20 4 way splitter	-6.35
20 dB attenuator	-20.00
Pulsar burst mixer	-6.00
Total path loss from Klystron to IFD (J2) input	-77.20

Table 4: IF Burst Mixer Path Losses

4A36 Optional attenuator to IFD (J1) Path	Path Loss (dB)
Cable loss from 2A4 low noise amplifier to 4A36 Optional attenuator	-3.46 dB
4A36 Optional attenuator	0.00
4DC2 Directional coupler	0.00
4A4 Pre-select bandpass filter	-2.22
4A5 Mixer/Preamp	19.79
3 dB IFD attenuator	-3.00
Total path loss from Optional attenuator input to IFD (J1) input	11.11

Table 5: IF Receiver Path Losses

UD2 Components	Path Loss (dB)
2A3 Receiver Protector	-0.65
2A1A3FL1 Bandpass Filter	-0.50
2A4 Low Noise Amplifier (LNA) 28 dB gain	27.88
Total path loss from Receiver Protector in to LNA out	26.73

Table 6: UD2 Path Losses

Path Losses

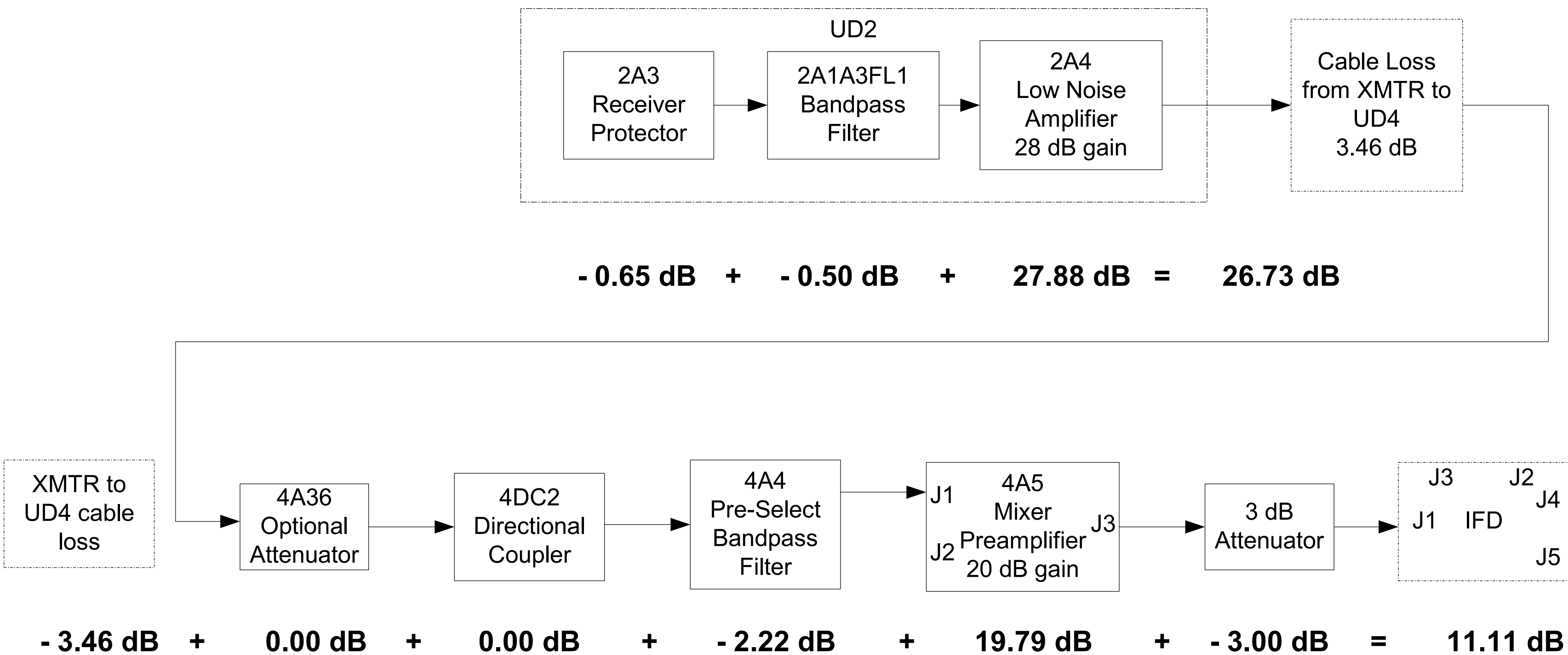


Figure 1

Table 7 and Figure 2 shows the new RF configuration that we are proposing using a 6 dB directional coupler instead of a RF splitter. The most significant results are highlighted in bold text. Table 8 and Figure 3 shows the RF test path and signal losses in the UD4 cabinet. The signal strengths were calculated by adding the path losses to each RF component signal input. Figure 3 shows the normal test path signal strength.

Table 7 shows how the 6 dB directional coupler causes a 1.8 dB loss in the STALO signal. The STALO signal is reduced to 13.55 dBm. This is a significant improvement when compared to the RF splitter's 3.5 dB loss and STALO output signal of 11.85 dBm. The minimum STALO signal for the mixer preamp is 14.0 dBm. Further, a directional coupler, rather than an active splitter, is much more feasible in terms of costs and MTBF.

From Table 7, the Pulsar burst mixer peak RF normal input (16.58 dBm) is much higher than the required 1 dB compression point value of 4 dBm. This generates an input IF signal of 10.58 dBm; well above the upper limit of 6.5 dBm required for optimal dynamic range at the IFD J2 input. This signal level could cause saturation problems for the phase linearity of the IFD. The addition of attenuators at the J2 input would attenuate the signal to the proper dynamic range of the IFD.

Bill Urell conducted a test at KCRI attenuating the STALO signal between 3 and 6 dB to determine how it might affect the Legacy system. His tests showed, lowering STALO signal by 3.7 dB, did not affect the IFD's system noise temperature or dynamic range. A 6 dB signal loss did result in a higher noise temperature. The test results showed signal losses greater than 3.7 dB would eventually affect the receiver's noise figure.

RF component	Expected Signal	Expected RF signal using field data Path losses			
		Normal Peak Power (dBm)	(Normal - Duty Cycle)[a] (dBm)	Min. Peak Power (dBm)	Max. Peak Power (dBm)
4A1 Xmtr RF out 4A1 STALO out 4A1 Test RF out 4A1 COHO out	13.00 ± 1.25 15.00 ± 0.75 23.00 ± 1.75 27.00 ± 1.00	13.00 15.35 22.54 26.77	13.00 15.35 22.54 26.77	11.75 14.65 21.92 26.36	14.25 16.05 23.16 27.18
26 dB attenuator IFD in **26 dB attenuator IFD out (IFD J3 input)**	 -8.00 to +2.00	26.77 **0.77**	26.77 **0.77**	26.36 **-0.14**	27.18 **1.68**
6 dB Directional coupler STALO in **6 dB Directional coupler STALO 1 (6 dB loss) out** **6 dB Directional coupler STALO 2 (1.8 dB loss) out**	 15.00 ± 1.00	15.35 **9.35** **13.55**	15.35 **9.35** **13.55**	14.65 **8.65** **12.85**	16.05 **10.05** **14.25**
AT33 6 dB attenuator in {Xmtr pwr. – UD3 att. (88.45 – 39.67)} AT33 6 dB attenuator out		48.78 42.93	(20.66)[a] (14.81)[a]	48.64 42.53	48.92 43.33
4A20 4 way splitter in 4A20 4 way splitter 6 dB loss (J5) out		42.93 36.58	(14.81)[a] (8.46)[a]	42.53 35.97	43.33 37.19
20 dB attenuator (RF 4 way splitter out) in 20 dB attenuator out	35.00 ± 1.00	36.58 16.58	(8.46)[a] (-11.54)[a]	35.97 15.47	37.19 17.69
Pulsar Burst mixer RF in **Pulsar Burst mixer STALO in** **Pulsar Burst mixer IF out (IFD J2 input)**	 -12.00 to +1.00	**16.58** **9.35** **10.58**	**(-11.54)[a]** **9.35** **(-17.54)[a]**	**15.47** **8.65** **9.27**	**17.69** **10.05** **11.89**
2A3 Receiver protector incoming signal 2A3 Receiver protector out		-40.00 -40.65	-40.00 -40.65	-40.00 -40.88	-40.00 -40.42
2A1A3FL1 Receiver bandpass filter in 2A1A3FL1 Receiver bandpass filter out		-40.65 -41.15	-40.65 -41.15	-40.88 -41.58	-40.42 -40.72
2A4 Low noise amplifier 28 dB gain in 2A4 Low noise amplifier 28 dB gain out		-41.15 -13.27	-41.15 -13.27	-41.58 -14.17	-40.72 -12.37
Cable loss from tower to UD4 (-3.46 dB)		-16.73	-16.73	-17.63	-15.83

4A36 Optional attenuator in 4A36 Optional attenuator out		-16.73 -17.32	-16.73 -17.32	-17.63 -19.02	-15.83 -15.62
4DC2 Directional coupler in 4DC2 Directional coupler out		-17.32 -17.32	-17.32 -17.32	-19.02 -19.02	-15.62 -15.62
4A4 Pre-select bandpass filter in 4A4 Pre-select bandpass filter out		-17.32 -19.54	-17.32 -19.54	-19.02 -21.61	-15.62 -17.47
4A5 20 dB gain mixer/preamp STALO 2 (J2) in 4A5 20 dB gain mixer/preamp (J1) in 4A5 20 dB gain mixer/preamp out	15.00 ± 1.00	**13.55** -19.54 0.25	**13.55** -19.54 0.25	**12.85** -21.61 -2.32	**14.25** -17.47 2.82
IFD 3 dB attenuator in **IFD 3 dB attenuator out (IFD J1 input)**	-86.00 to +8.50	0.25 **-2.75**	0.25 **-2.75**	-2.32 **-5.82**	2.82 **-0.18**

Table 7: RF signal strength

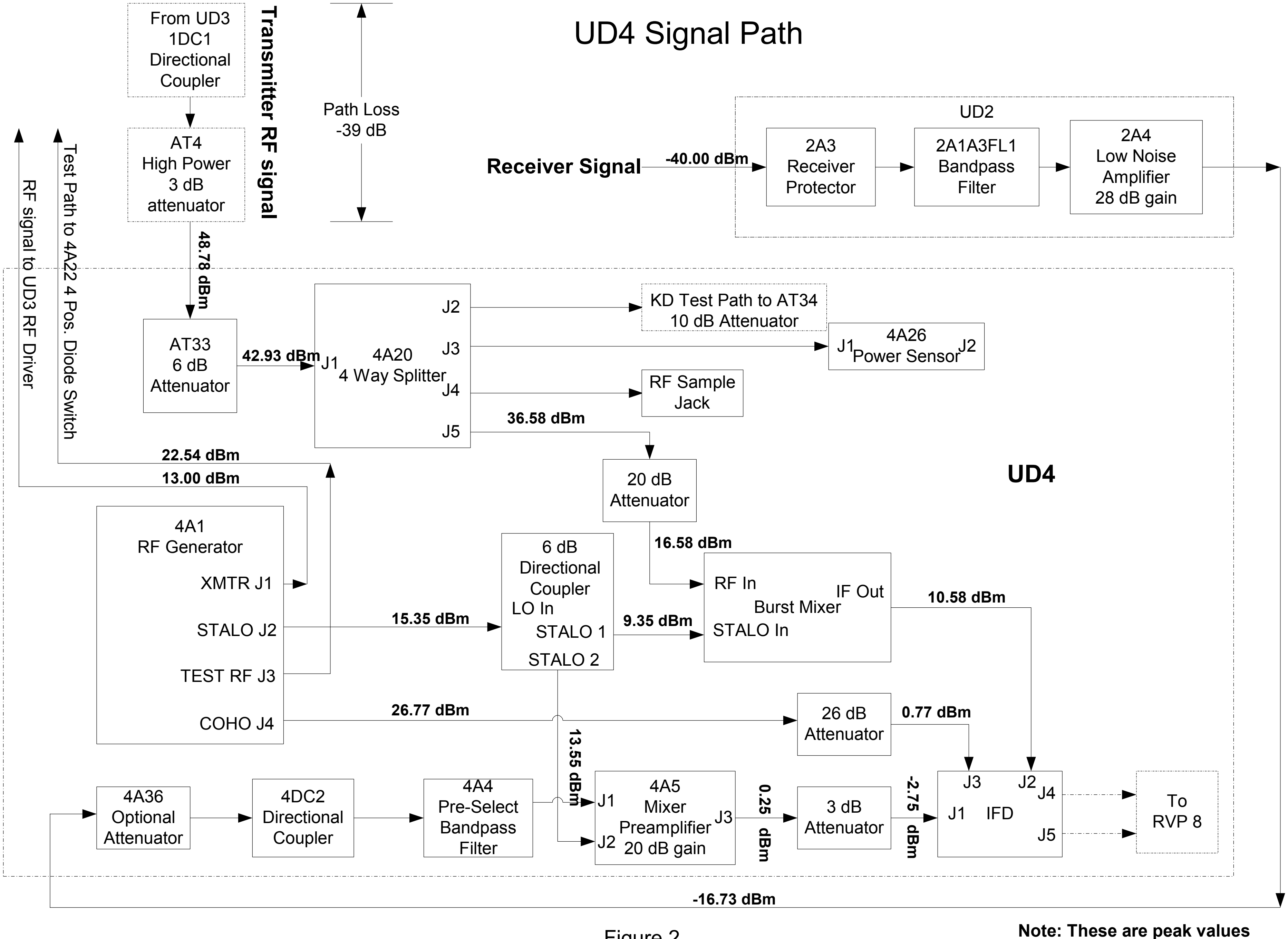

UD4 Signal Path
From UD3 1DC1 Directional Coupler
Transmitter RF signal
Path Loss -39 dB
AT4 High Power 3 dB attenuator
48.78 dBm
RF signal to UD3 RF Driver
Test Path to 4A22 4 Pos. Diode Switch
UD2
Receiver Signal
-40.00 dBm
2A3 Receiver Protector
2A1A3FL1 Bandpass Filter
2A4 Low Noise Amplifier 28 dB gain
AT33 6 dB Attenuator
42.93 dBm
J1 4A20 4 Way Splitter
J2
J3
J4
J5
KD Test Path to AT34 10 dB Attenuator
J1 4A26 Power Sensor J2
RF Sample Jack
36.58 dBm
22.54 dBm
13.00 dBm
20 dB Attenuator
UD4
4A1 RF Generator
XMTR J1
STALO J2
TEST RF J3
COHO J4
16.58 dBm
6 dB Directional Coupler
LO In
STALO 1
STALO 2
15.35 dBm
9.35 dBm
RF In
Burst Mixer
IF Out
STALO In
10.58 dBm
26.77 dBm
26 dB Attenuator
0.77 dBm
13.55 dBm
4A36 Optional Attenuator
4DC2 Directional Coupler
4A4 Pre-Select Bandpass Filter
J1
J2
4A5 Mixer Preamplifier 20 dB gain
J3
0.25 dBm
3 dB Attenuator
-2.75 dBm
J3
J2
J4
J1
IFD
J5
To RVP 8
-16.73 dBm
Note: These are peak values

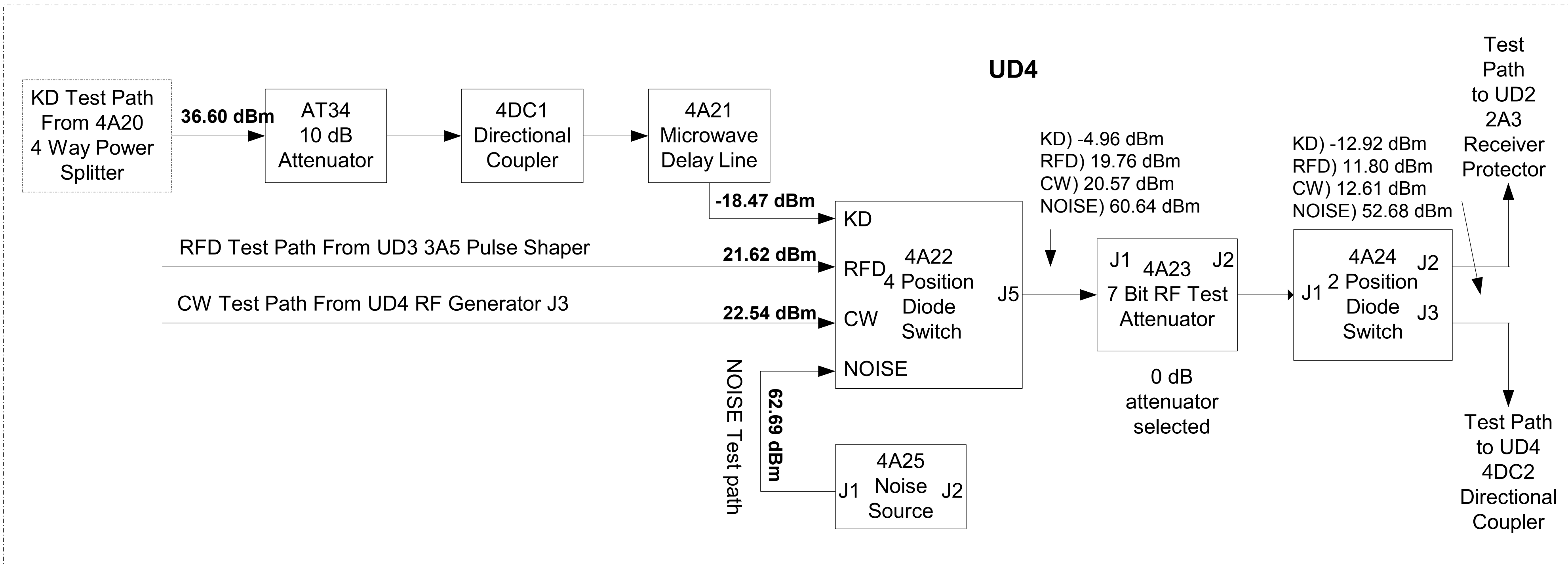
Figure 2

RF component	Expected RF signal using field data path losses			
	Normal Peak Power (dBm)	(Normal - Duty Cycle)[a] (dBm)	Min. Peak Power (dBm)	Max. Peak Power (dBm)
4A20 4 way splitter in	42.93	(14.81)[a]	42.53	43.33
4A20 4 way splitter 6 dB loss *KD Test path* (J2) out	36.60	(8.48)[a]	36.00	37.20
4A20 4 way splitter 6 dB loss (J3) out	36.55	(8.43)[a]	35.93	37.17
4A20 4 way splitter 6 dB loss (J4) out	35.66	(7.54)[a]	34.73	36.59
AT34 10 dB attenuator *KD Test path* in	36.60	(8.48)[a]	36.00	37.20
AT34 10 dB attenuator *KD Test path* out	26.37	(-1.75)[a]	25.54	27.20
4DC1 Directional coupler *KD Test path* in	26.37	(-1.75)[a]	25.54	27.20
4DC1 Directional coupler *KD Test path* out	26.37	(-1.75)[a]	25.54	27.20
4A21 Microwave delay line *KD Test path* in	26.37	(-1.75)[a]	25.54	27.20
4A21 Microwave delay line *KD Test path* out	-18.47	(-46.59)[a]	-21.09	-15.85
4A22 4 position diode switch 14 dB gain *KD Test path* (KD - J5) out	-4.96	(-33.08)[a]	-8.62	-1.30
4A22 4 position diode switch *RFD Test path* (RFD - J5) out	19.76	19.76	19.05	20.47
4A22 4 position diode switch *CW Test path* (CW - J5) out	20.57	20.57	19.64	21.50
4A22 4 position diode switch *NOISE Test path* (NOISE - J5) out	60.64	60.64	59.47	61.81
4A23 RF 6 dB Test attenuator *KD Test path* (J2) out	–10.97	(-39.09)[a]	-15.08	-6.86
4A23 RF 6 dB Test attenuator *RFD Test path* (J2) out	13.75	13.75	12.59	14.91
4A23 RF 6 dB Test attenuator *CW Test path* (J2) out	14.56	14.56	13.18	15.94
4A23 RF 6 dB Test attenuator *NOISE Test path* (J2) out	54.63	54.63	53.01	56.25

4A24 2 position diode switch *KD Test path* (J2) out	-12.92	(-41.04)[a]	-17.23	-8.61
4A24 2 position diode switch *KD Test path* (J3) out	-12.53	(-40.65)[a]	-16.85	-8.21
4A24 2 position diode switch *RFD Test path* (J2) out	11.80	11.80	10.44	13.16
4A24 2 position diode switch *RFD Test path* (J3) out	12.19	12.19	10.82	13.56
4A24 2 position diode switch *CW Test path* (J2) out	12.61	12.61	11.03	14.19
4A24 2 position diode switch *CW Test path* (J3) out	13.00	13.00	11.41	14.59
4A24 2 position diode switch *NOISE Test path* (J2) out	52.68	52.68	50.86	54.50
4A24 2 position diode switch *NOISE Test path* (J3) out	53.07	53.07	51.24	54.90

Table 8: RF Test Signal Strength

UD4 Test Path



Note: RFD Test path has 2.38 dB cable loss from XMTR to Diode switch

Figure 3

Note: These peak values

Conclusion

The analysis showed the most significant change occurred when a proposal was made to replace the RF splitter with a 6 dB directional coupler. The results indicated that a 6 dB directional coupler caused a lower STALO path loss. This is critical because of the IF mixer/preamp STALO input requirements. According to the mixer/preamp manufacturer, Microphase, a STALO signal significantly below the minimum requirements could affect the dynamic range and noise figure of mixer/pre-amp. Table 9 shows the advantages and disadvantages of using different RF components to compensate for the STALO losses.

A 6 dB directional coupler would appear as the most logical possible solution because it met the following requirements:

1. Lowest RF component cost (90.00 each)
2. Lower attenuation and insertion losses (1.8 dB) than a passive splitter (3.5 dB)
3. Faster installation time (only 1 component required)
4. COTS item
5. High MTBF
6. Passive component (No power required and less noise induced)

A 6 dB directional coupler does reduced the STALO signal by 1.8 dB into the IF mixer/preamp. However, Bill Urell's STALO attenuation tests on Legacy equipment at KCRI showed attenuating the STALO signal up to 3.7 dB caused no deterioration in the IFD's dynamic range or noise figure. Further tests need to be run with newer Sigmet equipment (RVP8 and I/O panel) to determine if these new RF components could affect the radar system.

Options	Advantages	Disadvantages	Estimated costs
1) Passive splitter	Low cost COTS item Less noise induced Faster installation time (Only 1 component required)	Lower STALO signal (3.5 dB loss) at both output ports	100 ea.
2) Active splitter	Higher STALO signal More stable IF mixer/preamp input	More noise induced More power consumption Higher phase noise Higher costs than passive components Lower MTBF	500 ea.
3) Modify SG1000	Allows for passive RF splitter to be used instead of active splitter	High costs Longer installation time More testing required on SG1000	8,000 for new engineering design 6,700 ea.
4) 6 dB Directional coupler	Lowest RF component cost COTS item Faster installation time (Only 1 component require Less noise induced	Lower STALO signal (1.8 dB loss) for mixer/preamp Lower STALO signal (6 dB loss) for burst mixer	90 ea.
5) Use separate components for mixer/pre-amplifier	COTS item Lower cost than option 3 Higher MTBF than active components	More parts required More systems testing required on each component	Mixer: 100 ea. Filter: 100 ea. Amplifier: 500 ea. Isolator: 200 ea.

6) Don't use burst mixer	Cheapest of all design scenarios No new parts required No reduction in STALO signal	Less stability in phase linearity for IFD Reduces signal processing flexibility Doesn't digitize burst pulse for other possible uses.	0
7) Increase RF generator STALO signal	Allows passive component use because of higher STALO signal	Increases probability of RF generator failure due to re-working current generator and shipping Longer installation time Logistic problems: Only NRC can implement these changes. Requires authorization and procedures for upgrading RF generator.	Shipping: 200 ea Repair: 400 ea.

Table 9: Options